Searches for electroweak production of supersymmetric gauginos and sleptons with the ATLAS detector

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on behalf of ATLAS collaboration

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SUSY introduction

Recent ATLAS EWK SUSY results:
✓ Direct stau production
✓ Same-sign stauino pair production via vector boson fusion (VBF)
✓ Compressed spectra in direct production

Conclusion
Remaining issues after higgs-boson discovery:
- Hierarchy problem, Dark Matter, Gravity, No gauge unification at higher scale

- **SuperSymmetry (SUSY)**: very appealing extension of SM to answer these questions.

- Limits of most models probe masses up to ~900 GeV (squarks) and ~1.4 TeV (gluinos).

SUSY searches in the EWK sector provide a promising approach for new physics:
- low production cross-section but low hadronic activity.

**Experimental Parameters**
- 1-4 leptons, missing transverse energy ($E_T^{miss}$), 0-2 jets (or b-jets)
Search for direct stau production in events with at least two hadronic taus and missing transverse momentum using multivariate analysis technique

Direct stau production

- R-parity conservation scenario
- Experimental signature:
  - 2 opposite-sign taus, $E_T^{miss}$
- Using multivariate analysis (MVA) technique due to low cross-section
- Main backgrounds:
  - $W + \text{jets(1real+1fake)} \rightarrow$ normalized to data in dedicated WCR
  - multi-jet $\rightarrow$ ABCD estimation
  - Other sub-dominant $\rightarrow$ simulation

Illustration of the ABCD method
Direct stau production - results

- 95% CL exclusion limits on the cross-section for production of left-handed and right-handed stau pairs for various $\tilde{\chi}_1^0$ masses
- These limits on direct production of stau pairs improve upon the previous limits, particularly for stau masses below $\sim 150$ GeV.
Search for supersymmetry in compressed scenarios with two and three leptons and missing transverse momentum in the final state
SS C1C1 production via VBF

- **Experimental signature:**
  - 2SS-leptons, \( \geq 2 \text{jets}, E_T^{\text{miss}} \)
- **SM backgrounds:**
  - "prompt" leptons (diboson, H) \( \rightarrow \) MC simulation
  - Non-prompt (Fake) leptons \( (W+\text{jets, } t\bar{t}) \rightarrow \) Fake Factor Method
  - Charge-misID leptons \( \rightarrow \) measured from dedicated control region (CR)

### Signal selections

<table>
<thead>
<tr>
<th>( \ell ) flavor/sign</th>
<th>( \ell^\pm \ell^\pm, \ell^\pm \ell^\mp )</th>
</tr>
</thead>
<tbody>
<tr>
<td>jets</td>
<td>( \geq 2 )</td>
</tr>
<tr>
<td>central b-jets</td>
<td>( \geq 5 )</td>
</tr>
<tr>
<td>( E_T^{\text{miss}} ) \ (GeV)</td>
<td>( &gt; 120 )</td>
</tr>
<tr>
<td>( m_{T2} ) \ (GeV)</td>
<td>( &lt; 40 )</td>
</tr>
<tr>
<td>( m_{\ell\ell} ) \ (GeV)</td>
<td>( &lt; 100 )</td>
</tr>
<tr>
<td>( p_{Tj} ) \ (GeV)</td>
<td>( &gt; 95 )</td>
</tr>
<tr>
<td>( m_{jj} ) \ (GeV)</td>
<td>( &gt; 350 )</td>
</tr>
<tr>
<td>( \eta_{j1} ) . ( \eta_{j2} )</td>
<td>( &lt; 0 )</td>
</tr>
<tr>
<td>(</td>
<td>\Delta\eta_{jj}</td>
</tr>
<tr>
<td>( p_{T\ell}/p_T )</td>
<td>( &lt; 0.4 )</td>
</tr>
<tr>
<td>( p_{Tj^1}/p_T )</td>
<td>( &lt; 1.9 )</td>
</tr>
<tr>
<td>( p_{T\ell}/p_T )</td>
<td>( &lt; 0.35 )</td>
</tr>
</tbody>
</table>

\( E_T^{\text{miss}} \) \ text{ in SR2\ell-2}

\( m_{jj} \) \ text{ in SR2\ell-2}
SS C1C1 production via VBF - results

- 95% CL exclusion limits on the cross-section for VBF production of $\tilde{\chi}_1^\pm$ $\tilde{\chi}_1^\mp$. The limits have been set with respect to the mass difference between the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$.
- The best observed upper limit is found for $\tilde{\chi}_1^\pm$ mass of 120 GeV and $m(\tilde{\chi}_1^\pm)-m(\tilde{\chi}_1^0) = 25$ GeV.

Slightly stronger sensitivity for higher $\tilde{\chi}_1^\pm$ masses
Compressed scenarios

- SUSY scenarios which have **small mass difference** between sparticles and neutralinos:
  - Final state with low-momentum leptons
- **Difficulties:**
  - Low mass splitting
  - Soft decay products
  - SM-like
- Re-optimized ATLAS analysis targeting compressed spectra:
  - 2 OS light leptons
  - 2 SS light leptons
  - 3 light leptons
OS 2l – event selection & BG estimation

- Experimental signature: 2OS-lepton, $E_T^{miss}$
- Two SRs requiring a high pT ISR jets, sensitive to small and moderate mass splittings
- Discriminate variable “super-razor” used
- SM backgrounds:
  - irreducible background (WW, top, ZV) -> normalized MC in dedicated CRs
  - Reducible background (all fake sources) -> Matrix Method
  - Others (Higgs, Z+jets) -> MC simulation
**SS 2l – event selection & BG estimation**

- **Experimental signature:** 2SS-lepton, $E_T^{miss}$
- Eight BDTs are trained to cover four different mass splittings for $m(\tilde{\chi}_1^\pm) - m(\tilde{\chi}_0^\pm) = 20, 35, 60, 100\text{GeV}$.
- One region for each mass splitting requires an ISR jet, the others apply a jet-veto.
- **SM backgrounds:**
  - “prompt” leptons (diboson, triboson, $t\bar{t}V$, $tZ$, H) -> MC simulation
  - Non-prompt(Fake) leptons -> Matrix Method(except $W\gamma$ by MC prediction)
  - Charge-Flip leptons -> charge misID rate measured from CRs
3I – event selection & BG estimation

- **Experimental signature:**
  \[ \text{3 leptons (1 same-flavor OS pair), } E_T^{\text{miss}} \]

- **2 SRs with low pT leptons** to target mass splittings of 4-15 and 15-25GeV, 2 SRs which request a jet with pT>50GeV to target ISR events for both splitting regions

- **SM backgrounds:**
  - Irreducible (prompt) leptons
    - diboson, triboson, H -> MC simulation
  - Reducible (Fake) leptons
    - V+jets, WW, top, \( t \bar{t} \) -> Matrix Method
Re-optimized analysis nicely complements the already published one in the region of low mass splittings close to the diagonal.
• Re-optimized analysis nicely complements the already published one in the region of low mass splittings close to the diagonal.

• The combination of the new analyses give an improved sensitivity to compressed scenarios up to $\tilde{\chi}_1^\pm$ masses of 250 GeV.
Various searches in EWK SUSY sector at ATLAS:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Newly updated results for EWK SUSY searching presented.

No significant excess observed beyond SM expectation.

Higher sensitivity and expanding exclusion/discovery contour is expected with 13/14TeV LHC RUN2 data
Extra slides
Super razor variables

- Iteratively transformed observable momenta.
- At each step, determine the next transformation by making boost invariant guesses for unknown parameters.
  - 1st transformation: extract variable sensitive to invariant mass of total event
  - 2nd transformation: extract variable sensitive to invariant mass of squark

\[ M_\Delta \equiv \frac{m_{\tilde{l}}^2 - m_{\tilde{\chi}^0}^2}{m_{\tilde{l}}} \]
Search for direct pair production of a chargino and a neutralino decaying to the 125 GeV Higgs boson

http://arxiv.org/abs/1501.07110
Electroweakino SUSY Searches via higgs decay

- Direct pair production of $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ may be the dominant production of supersymmetric particles if the superpartners of the gluon and quarks are heavier than a few TeV.

- The decay to the Higgs boson dominants when:
  - the mass splitting between the two lightest neutralinos is larger than the Higgs boson mass
  - the higgsinos are much heavier than the winos, causing the composition of the $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_2^0$ to be wino-like and nearly mass degenerate.

- The analysis is based on 20.3 fb-1 of $\sqrt{S} = 8$ TeV pp collision data.
**lbb channel – event selection & bkg estimation**

- **Experimental signature:** 2b-jets, 1lepton, $E_T^{\text{miss}}$
- **Discriminating variables:** $E_T^{\text{miss}}, m_{CT}, m_W$
- **2 Signal Regions(SR) defined for the channel in 5 bins of $M_{bb}$**
- **Main background $tt\bar{t}$ and W+jets taken from simulation and normalized to data from dedicated Control Regions(CR)**
- **Multi-jet BG is estimated from data using Matrix Method**

<table>
<thead>
<tr>
<th></th>
<th>SRlbb-1</th>
<th>SRlbb-2</th>
<th>CRlbb-T</th>
<th>CRlbb-W</th>
<th>VRlbb-1</th>
<th>VRlbb-2</th>
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</thead>
<tbody>
<tr>
<td>$n_{\text{lepton}}$</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$n_{\text{jet}}$</td>
<td>2-3</td>
<td>2-3</td>
<td>2-3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$n_{b\text{-jet}}$</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$ [GeV]</td>
<td>&gt; 100</td>
<td>&gt; 100</td>
<td>&gt; 100</td>
<td>&gt; 100</td>
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<tr>
<td>$m_{CT}$ [GeV]</td>
<td>&gt; 160</td>
<td>&gt; 160</td>
<td>100-160</td>
<td>&gt; 160</td>
<td>100-160</td>
<td>&gt; 160</td>
</tr>
<tr>
<td>$m_W$ [GeV]</td>
<td>100-130</td>
<td>&gt; 130</td>
<td>&gt; 100</td>
<td>&gt; 40</td>
<td>40-100</td>
<td>40-100</td>
</tr>
</tbody>
</table>
**\( \gamma\gamma \) channel – event selection**

- **Experimental signature:**
  - 2\( \gamma \), 1lepton, \( E_T^{\text{miss}} \)
- **Diphoton or single-lepton trigger**
- **2SRs defined for this channel**
- **non-Higgs SM BG**
  - template fit to the full \( M_{\gamma\gamma} \) distribution
- **Higgs SM BG:**
  - simulation

\[
m_{T_W^{\gamma\gamma}} = \sqrt{(m_W^W)^2 + 2E_T^W E_T^{\gamma\gamma} - 2p_T^W \cdot p_T^{\gamma\gamma}},
\]

<table>
<thead>
<tr>
<th></th>
<th>SR( \ell\gamma\gamma-1 )</th>
<th>SR( \ell\gamma\gamma-2 )</th>
<th>VR( \ell\gamma\gamma-1 )</th>
<th>VR( \ell\gamma\gamma-2 )</th>
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</thead>
<tbody>
<tr>
<td>( n_{\text{lepton}} )</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>( n_\gamma )</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>( E_T^{\text{miss}} ) [GeV]</td>
<td>&gt; 40</td>
<td>&gt; 40</td>
<td>&lt; 40</td>
<td>—</td>
</tr>
<tr>
<td>( \Delta \phi(W, h) )</td>
<td>&gt; 2.25</td>
<td>&gt; 2.25</td>
<td>—</td>
<td>&lt; 2.25</td>
</tr>
<tr>
<td>( m_{W^{\gamma\gamma}} ) [GeV]</td>
<td>&gt; 150</td>
<td>&lt; 150</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>and or</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( m_{T_W^{\gamma\gamma}} ) [GeV]</td>
<td>&gt; 80</td>
<td>&lt; 80</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

2015/8/26
SSll channel – object selection

- Experimental signature:
  - 2jets, SS2l, $E_T^{miss}$
- Dilepton trigger
- SM background:
  - "prompt" leptons (WZ/ZZ) -> MC simulation
  - Non-prompt(Fake) leptons -> Matrix Method
  - Other: charge-misID leptons -> misID probability measured from data

Selection requirements for the signal regions of the same-sign dilepton channel.

<table>
<thead>
<tr>
<th>Lepton flavours</th>
<th>$n_{jet}$</th>
<th>ee</th>
<th>ee</th>
<th>$\mu\mu$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
<th>$e\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leading lepton $p_T$ [GeV]</td>
<td>&gt; 30</td>
<td>&gt; 30</td>
<td>&gt; 30</td>
<td>&gt; 30</td>
<td>&gt; 30</td>
<td>&gt; 30</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>Sub-leading lepton $p_T$ [GeV]</td>
<td>&gt; 20</td>
<td>&gt; 20</td>
<td>&gt; 20</td>
<td>&gt; 30</td>
<td>&gt; 30</td>
<td>&gt; 30</td>
<td>&gt; 30</td>
</tr>
<tr>
<td>$</td>
<td>m_{\ell\ell} - m_Z</td>
<td>$ [GeV]</td>
<td>&gt; 10</td>
<td>&gt; 10</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\Delta\eta_{\ell\ell}$</td>
<td>-</td>
<td>-</td>
<td>&lt; 1.5</td>
<td>&lt; 1.5</td>
<td>&lt; 1.5</td>
<td>&lt; 1.5</td>
<td>&lt; 1.5</td>
</tr>
<tr>
<td>$E_T^{miss,rel}$ [GeV]</td>
<td>&gt; 55</td>
<td>&gt; 30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>$m_{eff}$ [GeV]</td>
<td>&gt; 200</td>
<td>-</td>
<td>&gt; 200</td>
<td>&gt; 200</td>
<td>&gt; 200</td>
<td>&gt; 200</td>
<td>&gt; 200</td>
</tr>
<tr>
<td>$m_T^{max}$ [GeV]</td>
<td>-</td>
<td>&gt; 110</td>
<td>&gt; 110</td>
<td>-</td>
<td>&gt; 110</td>
<td>&gt; 110</td>
<td>&gt; 110</td>
</tr>
<tr>
<td>$m_{\ell\ell}$ or $m_{\ell\ell,j}$ [GeV]</td>
<td>&lt; 90</td>
<td>&lt; 120</td>
<td>&lt; 90</td>
<td>&lt; 120</td>
<td>&lt; 90</td>
<td>&lt; 120</td>
<td>&lt; 120</td>
</tr>
</tbody>
</table>
results and interpretation

- Region $m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0) < 140$ GeV is largely due to SRlbb-1, while the $\gamma\gamma$ channel being the best:
  - targeting models with small mass splitting between the neutralinos
- Region $m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0) = 240$ GeV is driven by SRlbb-2
  - designed for larger mass splitting.
- Region $m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0) = 170$ GeV all channel shows close sensitivity.

- Observed and expected 95% CL upper limits on the X-section normalized by the simplified model prediction as a function of the common mass $m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0)$ at $m(\tilde{\chi}_1^0) = 0$. 
results and interpretation

- The combination of these independent searches improves the sensitivity significantly by extending the 95% CL exclusion region to $m(\tilde{\chi}_1^0) = 250$ GeV.

- Observed and expected 95% CL exclusion region in the mass plane of $m(\tilde{\chi}_1^\pm, \tilde{\chi}_2^0)$ v.s. $m(\tilde{\chi}_1^0)$. 

2015/8/26
Search for exotic Higgs-boson decays in events with at least one photon, missing transverse momentum, and two forward jets
Searches via exotic higgs decaying to $\gamma(\gamma\gamma) + LSP$

- Depending on the Higgs-boson production cross section, $BF(h\rightarrow BSM)$ could be $O(50\%)$. SUSY extensions to the SM can explain the mass of the Higgs-boson and address the hierarchy problem.

- In certain extensions the Higgs-boson is predicted to decay into SUSY particles.

- Gauge mediated supersymmetry breaking (GMSB) model:
  - H decay to a nearly massless gravitino $\tilde{G}$ (LSP) and a $\tilde{\chi}_1^0$ (NLSP)
  - $M(h)/2 < M(\tilde{\chi}_1^0) < M(h)$

- Next-to-Minimal Supersymmetric Standard Models (NMSSM):
  - H decay to a nearly massless $\tilde{\chi}_2^0$ (NLSP) and a $\tilde{\chi}_1^0$ (LSP)
  - $M(h)/2 < M(\tilde{\chi}_2^0) < M(h)$

- Case also considered as fig.b:
  - Diphoton-MET signature
  - $M(\tilde{\chi}_1^0) < M(h)/2$ or $M(\tilde{\chi}_2^0) < M(h)/2$
event selection & bkg estimation

- Experimental signature:
  - $\geq 1$ photon,
  - VBF production (2 forward well separated jets)

- Most selection requirements were optimized using the Validation Region

- SM BG:
  - $\gamma$+jets, multi-jets, W/Z+$\gamma$, W/Z+jets, W→$e\nu$, others (WW, WZ, ZZ, ttbar)

- Dominant BG from $\gamma$+jets, multi-jets background estimated using data-driven ABCD

- Other BG taken from simulation and normalized to data in dedicated CR.

Background estimation strategy

Signal selections

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Data</th>
<th>$(m_{NLSP}, m_{LSP}) = (100, 0)$ GeV signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data quality and trigger</td>
<td>$1.53 \times 10^7$</td>
<td>337±4</td>
</tr>
<tr>
<td>Good vertex</td>
<td>$1.53 \times 10^7$</td>
<td>336±4</td>
</tr>
<tr>
<td>$E_T^{miss} &gt; 50$ GeV</td>
<td>$1.26 \times 10^7$</td>
<td>279±3</td>
</tr>
<tr>
<td>Selected photon $p_T &gt; 40$ GeV</td>
<td>$7.41 \times 10^3$</td>
<td>128±2</td>
</tr>
<tr>
<td>VBF $m_{jj} &gt; 400$ GeV and $</td>
<td>\Delta\eta_{jj}</td>
<td>&gt; 3.0$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Data</th>
<th>$(m_{NLSP}, m_{LSP}) = (100, 0)$ GeV signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>VBF jet $p_T &gt; 40$ GeV</td>
<td>6870</td>
<td>58.0±1.5</td>
</tr>
<tr>
<td>Lepton veto</td>
<td>6040</td>
<td>57.2±1.5</td>
</tr>
<tr>
<td>$\leq 1$ non-VBF jet</td>
<td>4620</td>
<td>50.4±1.4</td>
</tr>
<tr>
<td>$</td>
<td>\Delta(E_T^{miss}, VBF jet)</td>
<td>_{\text{min}} &gt; 1.4$</td>
</tr>
<tr>
<td>$</td>
<td>\Delta(E_T^{miss}, \text{non-VBF jet})</td>
<td>_{\text{min}} &lt; 2.0$</td>
</tr>
<tr>
<td>OPV</td>
<td>425</td>
<td>27.6±1.0</td>
</tr>
<tr>
<td>$</td>
<td>\vec{p}_T^{TOT}</td>
<td>&gt; 50$ GeV</td>
</tr>
<tr>
<td>$</td>
<td>\Delta(k_{F}, \gamma)</td>
<td>\leq 1.8$</td>
</tr>
<tr>
<td>VBF $m_{jj} &gt; 600$ GeV and $</td>
<td>\Delta\eta_{jj}</td>
<td>&gt; 4.0$</td>
</tr>
</tbody>
</table>
Due to excess in SR, observed limits are higher than expected ones.

Strong upper limits are obtained in $\gamma \gamma + E_T^{\text{miss}}$ final state also.

1.1 $\sigma$ excess is observed.
Upgrade study

Prospect for direct pair production of a chargino and a neutralino decaying via W and h in final states with one lepton, two b-jets and missing transverse momentum

ATL-PHYS-PUB-2015-032
Wh production – event selection & background

- Experimental signature:
  - 2b-jets, 1lepton, $E_T^{\text{miss}}$

- Cut-and count for LHC scenario

- BDT considered for HL-LHC scenario:

<table>
<thead>
<tr>
<th>Selection</th>
<th>SRA</th>
<th>SRB</th>
<th>SRC</th>
<th>SRD</th>
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</thead>
<tbody>
<tr>
<td># of leptons (e, $\mu$)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># b-tagged jets</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{bb}$ [GeV]</td>
<td>$105 &lt; m_{bb} &lt; 135$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># jets</td>
<td>2 or 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m_{CT}$ [GeV]</td>
<td>&gt; 200</td>
<td>&gt; 200</td>
<td>&gt; 300</td>
<td>&gt; 300</td>
</tr>
<tr>
<td>$m_T$ [GeV]</td>
<td>&gt; 200</td>
<td>&gt; 250</td>
<td>&gt; 200</td>
<td>&gt; 250</td>
</tr>
<tr>
<td>$E_T^{\text{miss}}$ [GeV]</td>
<td>&gt; 300</td>
<td>&gt; 350</td>
<td>&gt; 400</td>
<td>&gt; 450</td>
</tr>
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<td>$\langle \mu \rangle = 60$, 300 fb$^{-1}$ scenario</td>
<td>yes</td>
<td>yes</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$\langle \mu \rangle = 140$, 3000 fb$^{-1}$ scenario</td>
<td>–</td>
<td>–</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

(a) 300 fb$^{-1} < \mu > = 60$ scenario

(b) 3000 fb$^{-1} < \mu > = 140$ scenario
Wh production – sensitivity

$Z_n = \sqrt{2erf^{-1}(1-2p)}$

30% systematic uncertainty in assumption

- Expected 95% exclusion and discovery contours in the $m(\tilde{\chi}^0_1)$ v.s. $m(\tilde{\chi}^{\pm}_1, \tilde{\chi}^0_2)$ plane.
- Comparing the cut and count and MVA approaches BDT.
- An increase of integrated luminosity from 300 fb-1 to 3000 fb-1 extends significantly the discovery sensitivity potential for $\tilde{\chi}^{\pm}_1 \tilde{\chi}^0_2$ production and the exclusion sensitivity by about 200 GeV.